TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

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CONTENTS

	Page
Election of Officers and Council - - - -	46
Notes on Recent Meetings and Events - -	47
Forthcoming Events - - - - - - -	47
Applications for Membership - - - - -	48
Practical Electric Discharge Lamps; their General Applications and Recent Advances by L. J. Davies, M.A., B.Sc. -	49

VOLUME I—No. 4
APRIL 1936

32 VICTORIA STREET
LONDON SW1

ELECTION OF OFFICERS AND COUNCIL

SESSION 1936-1937

IN accordance with the procedure specified in the Articles of the Society, the following list of existing Officers and Members of Council, of vacancies occurring and of duly qualified persons nominated by the Council for vacancies about to occur in the offices of President, Vice-Presidents, Hon. Treasurer, Hon. Secretary, and Ordinary Members of Council, has been circulated to all Corporate Members of the Society.

In the event of any Members desiring to put forward other names, the Council will be pleased to receive such nominations, which should be made in accordance with the following rule (Article 48) :—

> "After the issue of the Council's list, and not later than the *15th day of April* next following, any ten Members (but no more than ten) may nominate any other duly qualified person to fill any such vacancy by delivering such nominations in writing to the Hon. Secretary, together with the written consent of such person to accept office if elected, but each such nominator shall be debarred from nominating any other person for the same office at such election."

Present Officers and Members of Council

President :—*Mr. A. W. Beuttell, M.I.E.E.*

Past Presidents :—

Mr. A. P. TROTTER, M.INST.C.E.
Sir JOHN HERBERT PARSONS, C.B.E., F.R.S.
Mr. D. R. WILSON, C.B.E.
Mr. C. C. PATERSON, O.B.E., M.I.E.E.
Dr. J. W. T. WALSH, M.A., D.SC., M.I.E.E.
Lt.-Col. K. EDGCUMBE, T.D., M.INST.C.E., M.I.E.E.
Sir FRANCIS GOODENOUGH, C.B.E.
Lt.-Com. HAYDN T. HARRISON, M.I.E.E., R.N.V.R.
MR. C. W. SULLY.
Mr. H. HEPWORTH THOMPSON.

Vice-Presidents :—

Mr. A. Cunnington (1933)
Mr. S. B. LANGLANDS (1934)
Dr. S. ENGLISH (1935)

Members of Council :—

Mr. W. A. BISHOP (1934)
Mr. H. BUCKLEY (1934)
Mr. D. CHANDLER (1935)
Mr. J. G. CLARK (1934)
Mr. A. C. Cramb (1933)
Dr. W. M. HAMPTON (1935)
Miss C. Haslett (1933)
Mr. GEORGE HERBERT (1934)
Mr. A. E. Iliffe (1933)
Mr. H. LINGARD (1935)
Mr. WALDO MAITLAND (1934)
Mr. F. W. PURSE (1935)
Mr. W. R. RAWLINGS (1935)
Mr. A. B. READ (1934)
Mr. T. E. Ritchie (1933)
Mr. JAMES SELLARS (1934)
Mr. F. C. SMITH (1935)
Mr. Ernest Stroud (1933)
Mr. G. H. Wilson (1933)

Hon. Secretary :—*Mr. J. Stewart Dow* (1928)

Hon. Treasurer :—*Mr. Percy Good* (1933)

Nominated by the Council to fill Vacancies

President :—Mr. A. CUNNINGTON, M.I.E.E.

Vice-President :—Mr. PERCY GOOD.

Members of Council :—

Mr. JUSTUS ECK.
Mr. W. J. JONES.
Dr. R. J. LYTHGOE.
Mr. HOWARD LONG.
Mr. A. R. MCGIBBON.
Prof. J. T. MACGREGOR-MORRIS.
Mr. E. W. MURRAY.
Mr. H. C. WESTON.

Hon. Secretary :—Mr. J. STEWART DOW.

Hon. Treasurer :—Mr. ERNEST STROUD.

The names in italics are those of retiring Officers or Members. The date in parentheses after each name indicates the date of election to Office or Membership of the Council.

NOTES ON RECENT MEETINGS AND EVENTS

General Meeting in London.

A general meeting was held in the Lecture Theatre of the Institution of Mechanical Engineers (Westminster), S.W.1, on Tuesday, February 11. The chair was taken by the President at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The chairman then called upon the following authors to present their papers:

Mr. H. Buckley on "The Classification of Symmetrical Light Distributions."

Mr. S. F. Dunkley and Mr. W. R. Stevens on "Thermal Tests of Illuminating Glassware."

Mr. S. F. Dunkley on "Heat Resisting Glassware with Special Reference to Tests for Quality."

The papers were presented in abstract and illustrated by lantern slides and by demonstrations and films showing the nature of the tests imposed.

Mr. Buckley, Mr. Dunkley, and Mr. Stevens having briefly replied to the ensuing discussion, a very cordial vote of thanks to the authors terminated the proceedings.

Section on Photometry.

The opening meeting of the Section on Photometry was held at the Westminster Technical Institute on February 4, Mr. H. Buckley presiding. An introductory address reviewing certain outstanding problems in photometry was delivered by Dr. J. W. T. Walsh. (*Light and Lighting*, March, 1935, pp. 76-78.) After a brief discussion on some of the problems mentioned by the lecturer, suggestions for future meetings and visits were invited. A vote of thanks to Dr. Walsh for his address and to the Westminster Technical Institute for its hospitality concluded the evening. The next meeting of the Section will take place on April 28. Those who desire to be informed of future meetings of the Section and who have not yet notified the honorary secretary (Mr. K. F. Sawyer, Watson House, Nine Elms Lane, London, S.W.8) should do so without delay.

Visit to the National Physical Laboratory.

A general meeting of the Society was arranged at the National Physical Laboratory, Teddington, on March 10. After the usual formal business had been transacted an address was given by Dr. E. H. Rayner (Superintendent of the Electrical Department), who, on behalf of the Director, welcomed the party. Dr. J. W. T. Walsh then gave an illustrated address explaining the chief features of the new photometric building (still in course of equipment), which was afterwards inspected by members. The thanks of the Society are due to Dr. Walsh and the staff for affording members of the Society an opportunity of taking part in this unofficial "housewarming." Dr. Walsh's address, with full description and illustrations of the new photometric building, will appear in the *Transactions* in due course.

Second Informal Meeting.

A second informal meeting, on similar lines to that which proved so successful in November last, was arranged to take place at St. Ermin's Hotel (St. James's Park, London, S.W.) on March 31, the evening being on this occasion devoted to a series of "Questions and Answers" on topics of general interest.

The Annual Dinner.

At the Annual Dinner of the Society, which took place at the Trocadero Restaurant on March 24, the attendance (approximately 320) was again a record and much in excess of that on any similar occasion in the past. As usual, kindred societies and institutions were well represented. The toast of "The Illuminating Engineering Society," to which the President responded, was proposed by Mr. J. M. Kennedy, President of the Institution of Electrical Engineers. The toast of "The Guests," undertaken by Mr. A. Cunnington, was associated with the names of Colonel W. Moncrieff Carr, President of the Institution of Gas Engineers, and Mr. A. Maurice Bell (President of the Association of Public Lighting Engineers). The remainder of the evening was, as usual, devoted to dancing and social intercourse.

Meetings in the North-West Area.

At a meeting held at the Engineers' Club, Manchester, on February 18, a paper on "The Application of Subjective Methods to Lighting Problems" was read, presented by Mr. R. Maxted.

On March 17 the paper by Mr. A. G. Brown and Mr. A. L. Whittenham on the lighting of "The World's Most Modern Fish Dock" (originally arranged for January 21, but deferred owing to the death of King George V.), was presented before an audience which included representatives of the staff of the Manchester Ship Canal, the Mersey Docks, and Harbour Board, and other bodies directly interested in the subject of the paper. It is hoped to summarise this and the preceding paper in the Journal in due course.

Another event arranged for members of the North-Western Area Local Section was a visit to the new photometric laboratory of the Manchester Corporation Gas Department on March 26.

Forthcoming Events.

April 7th.—Mr. R. C. Walker, Mr. L. H. McDermott and Mr. W. H. B. Hall on **Applications of Photo-Electric Cells in Illuminating Engineering** (Three Papers) *(General Meeting of the Illuminating Engineering Society, to be held in the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1);* **6.30 p.m.**

April 28th.—Lt.-Col. Kenelm Edgcumbe on **Recent Improvements in Integrating and Polar Curve Photometers (Photo-Electric Pattern)** and Mr. A. R. McGibbon and Mr. P. C. Sugg on **Photometric Apparatus for Lamp Testing.** *(Meeting of the Photometry Section of the Illuminating Engineering Society, to be held at the Westminster Technical Institute, Vincent Square, S.W.1);* **7 p.m.**

May 12th.—The **Annual Meeting** of the Illuminating Engineering Society. After the Presentation of the Annual Report and Accounts, and the Transactions of Formal Business, an **Address** will be delivered by Dr. Merry Cohu (Paris) reviewing **Progress in Illuminating Engineering in France.** *(At the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1);* **7 for 7.30 p.m.**

APPLICATIONS FOR MEMBERSHIP

Elections Completed.

The names of applicants announced at the general meeting on January 14, which have already appeared in the Transactions (Vol. 1, No. 2, p. 18, February, 1936) were read again at the general meeting on February 11, when these gentlemen were formally declared members.

The names of the following applicants for membership were presented at the general meeting of the Society on Tuesday, February 11, and were read again at the subsequent meeting held on Tuesday, March 10, when these gentlemen were also formally declared members of the Society:—

SUSTAINING MEMBER:—

The British Electric Lamps, Ltd. ..... Spencer Hill Road, Wimbledon, LONDON, S.W.19.
(*Representative*:—Mr. H. B. Arnold.)

CORPORATE MEMBERS:—

Gregory, H. W. ..... North Metropolitan Electric Power Supply Co., Electricity House, Kenton, MIDDLESEX.

Munns, J. H. ..... Benjamin Electric, Ltd., 44, Kings Road, Tottenham, LONDON, N.

Robinson, H. J. ..... Siemens Electric Lamps and Supplies, Ltd., 61, Navarino Mansions, Dalston Lane, LONDON, E.8.

COUNTRY MEMBERS:—

Dates, Prof. H. B. ..... Case School of Applied Science, Cleveland, OHIO, U.S.A.

Dixon, E. ..... City of Nottingham Lighting Department, 3A, George Street, NOTTINGHAM.

Howard, E. ..... City of Nottingham Lighting Department, 3A, George Street, NOTTINGHAM.

Wainwright, J. N. ..... Gas Offices, Halesown, WORCESTERSHIRE.

Waygood, Oscar C. Lewis's Ltd., Ranelagh Street, LIVERPOOL.

ASSOCIATE MEMBERS:—

Chater, W. C. Gas Light and Coke Company, Photometric Section, Watson House, Nine Elms Lane, LONDON, S.W.8.

Winslow, D. ..... Gas Light and Coke Company, Photometric Section, Watson House, Nine Elms Lane, LONDON, S.W.8.

AFFILIATED STUDENTS:—

Cole, G. F. ..... South Suburban Gas Company, 37, Goodrich Road, East Dulwich, LONDON, S.E.22.

Hatton, K. F. ..... E.L.M.A. Lighting Service Bureau, 73, Heybridge Avenue, STREATHAM, S.W.16.

Elections Pending.

The following names were presented at the general meeting of the Society on Tuesday, March 10, 1936:—

SUSTAINING MEMBER:—

Hanovia, Ltd. ..... Bath Road, Cippenham, SLOUGH.
(*Representative*:—J. E. Kolbert.)

CORPORATE MEMBERS:—

Angus, T. C. ..... London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, LONDON, W.C.1.

Childs, A. A. ..... 959, Forest Road, Walthamstow, LONDON, E.17.

Forsdyke, D. K. ..... 2, Holbrook Lane, Chislehurst, KENT.

Hawkins, J. Mortimer 26, Cheapside, LONDON, E.C.2.

Hollmann, O. E. E. .... 19, Brackley Road, Beckenham, KENT.

McWhirter, H. R. S. .... 47, Burnaby Gardens, Chiswick, LONDON, W.4.

Northwood, J. H. ..... 24, Henry's Avenue, Woodford Green, ESSEX.

Pelton, M. O. ..... British Cotton Industry Research Association, Shirley Institute, Didsbury, MANCHESTER.

Probst, E. S. ..... Pearce Signs, Ltd., New Cross Road, LONDON, S.E.

ASSOCIATE MEMBER:—

Lane, P. M. ..... 20, Ramillies Road, LONDON, W.4.

Lord, Chas. ..... 50, Carrwood Road, Pownall Park, Wilmslow, CHESHIRE.

COUNTRY MEMBERS:—

Jephcott, L. C. ..... 62, Murrayfield Road, HULL.

Jones, R. S. S. ..... Vibra-Lite, Ltd., Crescent Buildings, Montreal, CANADA.

Oxley, R. W. ..... Bexlea, Hebron Road, Middlesbrough, Yorks.

Wilyman, T. R. ..... Benjamin Electric, Ltd., 133, Church Lane, Handsworth Wood, BIRMINGHAM 20.

Privileged Membership.

In order that those outside the ranks of the Society who sympathise with its aims and objects and are in a position to render special service may have an opportunity of becoming familiar with its work, the Council has approved the proposal that a number of "Privileged Members," not exceeding twelve in each year, may be appointed. The distinction confers the privilege of attending meetings and receiving the Journal and Transactions but not those of voting or holding office and is subject to annual renewal.

The first two privileged members to be thus nominated by the Council are Dr. J. W. Whitaker (Croydon Polytechnic) and Mr. J. W. Bispham (London County Council Education Department).

PRACTICAL ELECTRIC DISCHARGE LAMPS. THEIR GENERAL APPLICATIONS AND RECENT ADVANCES

By L. J. DAVIES, M.A., B.Sc. *(Member)*
(Research Laboratory, The British Thomson-Houston Co., Ltd., Rugby).

(Paper read at the Meeting, on Tuesday, December 10th, 1935.)

Electrical phenomena in gases have been a subject of great scientific and popular interest ever since the first observations of them were made. The processes accompanying the conduction of electricity through a gas are usually so complex that even now physicists would claim to have unravelled but a small part of their complications, but as some form of compensation, they are generally accompanied by the emission of visible radiations of a rich and varied assortment that both physicist and layman can enjoy, and which engineers can utilise for the extension and the benefit of the art of lighting. Because the electric discharge lamp is such a fascinating study in itself and of such potential utility it finds no lack of commentators, and a wealth of recent scientific and technical papers testifies to its importance, and the amount of scientific and industrial research that is being devoted to it.

In writing this paper it has been assumed that there is no need to reiterate the reasons for this importance, nor to describe the elementary physics of the discharge lamp. If an explanation is needed for the presentation of a further paper on discharge lamps for this paper it is this:—

The electric discharge lamp is no longer a thing with possibilities only, for the illuminating engineer to try out in a tentative way on an experimental scale. Electric discharge lamps have definitely taken their place as technical, industrial, and commercial articles, made in a number of types and sizes, each well defined, and available for specific uses in well-recognised ways. However, the types available are rather diverse and include low pressure mercury vapour lamps (plain, and through various coloured glasses), high pressure mercury vapour lamps (and soon, perhaps, super high pressure mercury lamps), sodium vapour lamps, hot cathode neon lamps, and various modified and "colour" modified mercury lamps. In addition to the fixation of certain types of discharge lamps there is continual and increasing activity in industrial research laboratories on this subject, likely to bear valuable results for the near future. Such results are not likely to supplant the existing standardised discharge lamps, but rather to add further types, increasing the field of application until eventually they may extend over the whole range of illuminating engineering, from cinema projection to domestic lighting.

Because of the different gases used in the various types, the mechanism of the production of light is different, resulting in various shapes and sizes of bulbs, and of electrode design to secure the maximum efficiency for each gas. As a further consequence, the electrical characteristics and the auxiliary gear required differ for the various types. While the relative importance and the fields of utilisation of the various lamps available are clear to the lamp physicist and maker, it is felt that the position may be confusing to those who have to accept lamps as they come and whose job it is to utilise the illumination from them. A further difficulty is the contemporary existence, always present in the earlier

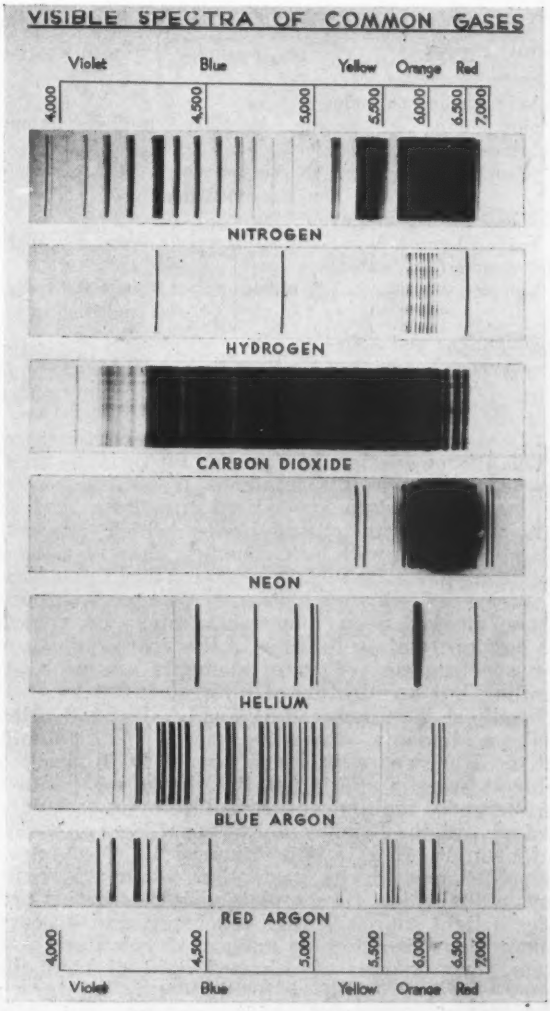

Fig. 1. Visible spectra of some common gases.

stages of development and utilisation of any device, of alternative types having the same functions.

The object of this paper, therefore, is to give to the illuminating engineer and the interested user a practical view-point of the present position of the electric discharge lamp. The matter is treated under three main headings. The first of these deals with some *general principles of discharge lamp design*, which attempts to explain certain features met with in the subsequent section, e.g., why lamps of the same wattage but of different types differ so largely in size and shape. The second section classifies and describes lamps under their main *applications*, and the third deals with some *recent advances in discharge lamp design and technique*.

General Design Principles.

A rough classification of existing lamps can be made as shown in Table I. below.

TABLE I.

Type.	Usual Fillings.	Main Use.
Cold cathode, cathodic glow Lamps	Neon.	Indicator Lamps.
Cold cathode positive column Lamps ...	Neon, mercury, helium, nitrogen.	Advertising.
Hot cathode (separately heated) Lamps ...	Neon, mercury.	Flood Lighting.
Hot cathode (Arc heated) Lamps	Mercury, sodium.	Street and Industrial Lighting.
Combination and Miscellaneous Lamps ...	Mercury.	As above, Medical and Special Uses.

The primary design determining factor is the filling gas used, though this influence is not so marked in lamps of certain specialised functions, such as indicator and advertising lamps, which, however. will not be dealt with here. The first characteristic of any filling gas is its visible spectrum and the spectra of at least the following elements, nitrogen, hydrogen, carbon dioxide, neon, magnesium, and zinc, contain the possibility of useful lines in the visible spectrum. The spectrograms of these elements are probably familiar. but a collection of interest, given by H. C Rentschler[1], is reproduced here (Figs. 1 and 2). Most of these elements, either because of low light output, or low vapour pressure, are of little practical value at present, and in practice the only gases used are *mercury, sodium, or neon*. Of these, sodium is used as a high efficiency source regardless of colour. and neon because it is a coloured light source of high efficiency for its particular colour. Mercury plays a dual rôle. Its complete visible radiation provides a light source of high efficiency, and its component lines, isolated by means of coloured glass filters, form sources of coloured light of high efficiency. Mercury differs in that it is used over a range of pressures, while sodium and neon are always operated at given operating pressures, which have been ascertained, mainly by experiment, to correspond to optimum light output conditions in the two gases respectively.

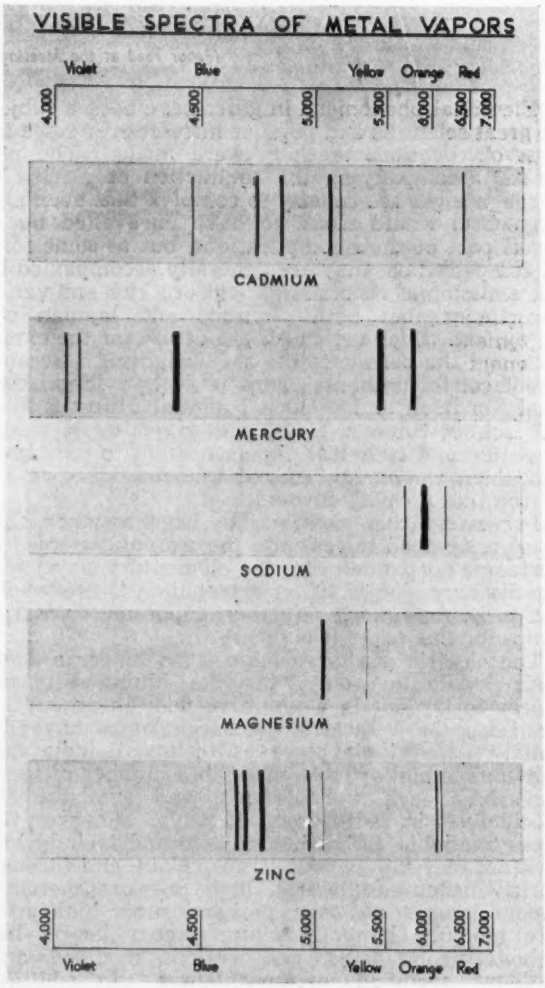

Fig. 2. Visible spectra of some metallic vapours.

The operating pressure and the nature of the gas, adjusted to obtain the required quality of radiation at the maximum efficiency, decide the characteristics of interest to the engineer using the lamps, viz., the electrical characteristics, the physical shape and size of the lamp for a given wattage, the nature of the cathodes, and the type and complication of the auxiliary gear required. The reasons for this may be seen from a brief consideration of some of the physical principles involved.

To produce light radiation from the atoms of a gas in an electrical discharge lamp it is necessary, (a), for the gas to conduct electricity, and, (b), for the atoms to receive energy. For the lamp to be a conductor

[1]H. C. Rentschler, Transactions I.E.S., xxix. June, 1934

there must be formed and maintained a supply of positive ions adequate to allow the flow of the desired electron current without space charge restrictions. In order for positive ions to be produced the atoms must receive energy, but from the point of view of light production the energy required for positive ion production is unnecessarily large and wasteful. To quote P. K. Darrow,[2] we have "that quality of molecules and atoms whereby they are able to receive, to store, and to deliver energy; to absorb light and to emit it; to induce other molecules to emit light or absorb it; to extract electrons from metals; to take energy from free electrons and use it in facilitating the discharges in a variety of interlocking ways—all this without being ionised. without for one moment ceasing to be uncharged and undisrupted particles." It is these various states that interest us from the point of view of light emission. Physicists and spectroscopists have evolved a convenient presentation for their study known as the energy level diagram.

The atom cannot receive or emit energy continuously, but only in discreet quantities, and can occur therefore at a series of specific energy levels each corresponding to a definite value of internal energy. It is the transition from a higher to a lower state of excitation that causes the emission of radiation. The energy difference of the two states between which a transition occurs decides the colour of the corresponding radiation, and, of course, whether it is invisible or visible. The value of the various energy levels and transitions and the possible ways in which these transitions can occur (the processes are very complicated) are characteristic of each atom. They are clearly of importance to the lamp designer who has to design a lamp for each particular type of atom in such a way as will secure the maximum number of transitions of the kind that result in visible radiation of the maximum luminous efficiency.

Since the atom can receive energy by the impact of an electron, the energy of which may be expressed as the voltage difference through which it is accelerated, the "equivalent" volt (1.591×10^{-12} erg.) forms a convenient energy unit.

The possible energy levels and transitions for any atom can best be visualised by representation as an energy-level diagram. In this the various excited states are shown as horizontal lines, the energy corresponding to each being given in equivalent volts against the left-hand ordinate. The possible transitions are shown as vertical lines, broken to allow of the insertion of the value in Angstrom units of the corresponding radiation. Equivalent volts and Angstrom units are both energy terms and are related by the equation.

$$\lambda = \frac{12336}{V}$$

It is of interest to note that the visible spectrum, viz., 4,000 to 7,000Å corresponds to equivalent voltage transition values of from 1.76 to 3.08 volts, and to observe the well-known eye sensitivity curve plotted against this basis, as shown in Fig. 3. To interpret easily, for our purpose, the energy level diagrams

[2]P. K. Darrow, Electrical Phenomena in Gases, p. 79.

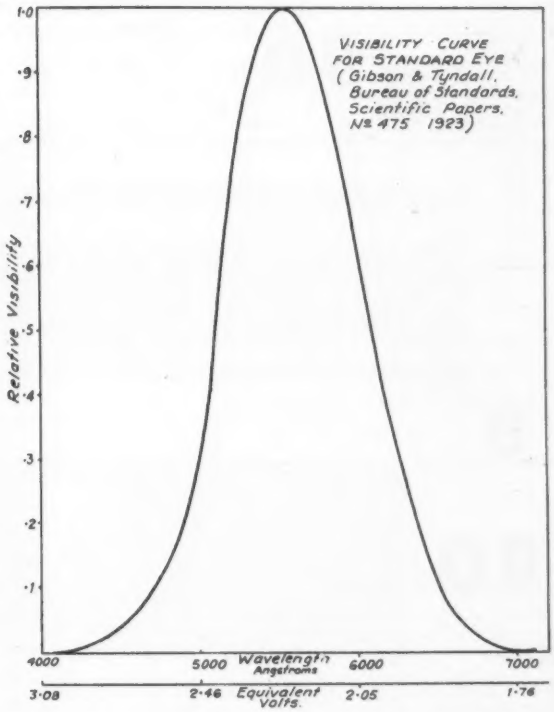

Fig. 3. Visual response of eye for light of various wavelengths.

we may indicate the luminous values of the various transitions by the thickness of the vertical lines, making these proportional to the height of the ordinates corresponding to the various voltages in the eye-sensitivity curve.

Very much simplified energy diagrams drawn in this way for mercury, sodium, and neon are shown in Fig. 4. These are illustrative only.

These show clearly the transitions of importance for light output. Each atom has a first excited state, and, taking the "neutral" level as a base, the equivalent volts and corresponding wave-lengths of these are, for the three kinds of atoms mainly used, as follows:—

Atom.	1st. Level Resonance.	Corresponding Wavelength A Units.
Sodium.	2.10	5890 : 5896
Mercury.	4.87	2537
	6.67	1850
Neon.	16.58	744
	16.77	736

In the case of sodium the line possesses the property of high visibility, but that for neon and mercury the lines are in the invisible ultra-violet, and to obtain visible radiations from the latter atoms

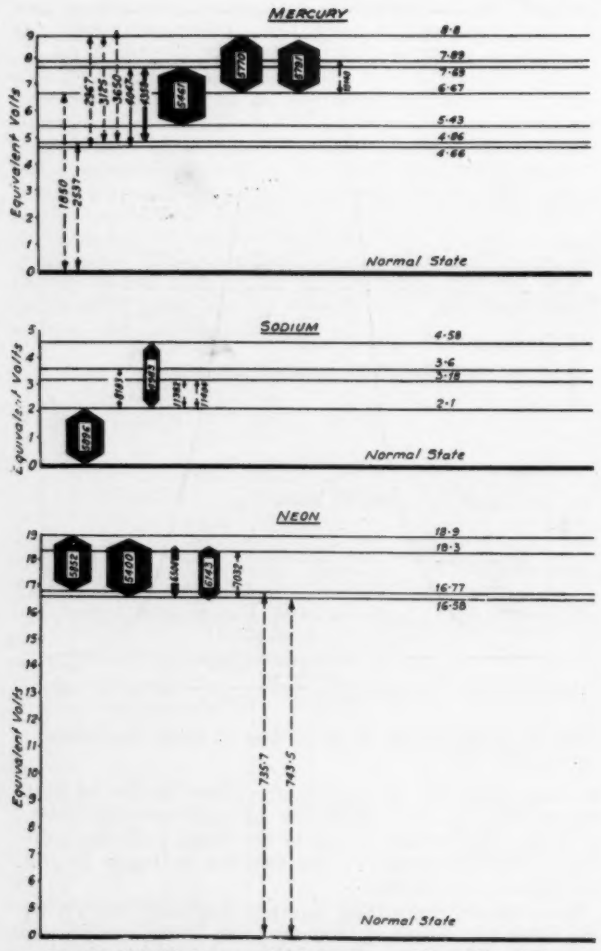

Fig. 4. Modified energy level diagrams. The width of the vertical "transition" lines is proportional to the visibility of the energy radiated.

one has to pass to a higher energy level and use a transition from this to the first level.

Should we, however, do this in the case of sodium, we shall immediately decrease our luminous output by radiating lines in the infra red.

RESONANCE RADIATION.

The problem in designing lamps for these two vapours is, for mercury, *to secure* the absorption of the resonance radiation and, for sodium, *to avoid* absorption of the resonance line, in both cases to prevent radiation of invisible energy.

The absorption of light from a resonance line by atoms of the same kind is a very real thing. It can be seen easily by observing a sodium vapour lamp through a flame carrying the vapour of a sodium salt. The flame absorbs the light from the lamp and appears black or sooty. A series of spectrograms of mercury at various pressures also demonstrate this absorption, as is shown in Fig. 5. It can be observed that as the pressure increases the resonance radiation of 2,537Å is absorbed. In a sodium vapour lamp the process of absorption and re-emission of light is proceeding continuously to such an extent that the light escape from the lamp takes place largely from the layer of vapour immediately next the inner surface of the lamp bulb. Within the body of the lamp the light is absorbed and re-emitted continuously without loss of energy. A striking experiment, which can only be seen properly in a well-darkened room, is to project a beam of light from a sodium vapour lamp into a bulb containing sodium vapour at the same pressure as in the lamp. The whole bulb glows with sodium light, with the intensity highest in the path of the beam. We have been able to take photographs* of a somewhat similar effect. Fig. 6 shows three sodium lamps, of which two are at operating temperature (but with the electrical supply switched off); the photograph is taken in the light of an ordinary tungsten lamp. Fig. 7 shows the same three lamps in the same condition, but in this case the photograph has been taken in the light of a sodium vapour lamp. The sodium lamps that are hot, i.e., contain the vapour of sodium at an appreciable pressure, have become self-luminous due to the absorption and re-emission of the D line radiation.

The absorption of this radiation without re-emission at the same wavelength, to form higher states of excitation with, as a consequence, a lower light output, occurs when the concentration of excited atoms, neutral atoms and electrons is high, i.e., at high vapour pressures and current densities.

It is this process of passing on energy, or cumulative ionisation, that enables a discharge, e.g., a hot cathode mercury vapour rectifier to operate with a voltage drop lower than the ionisation potential, although a copious supply of ions is present. It can occur in a sodium vapour lamp, and ionisation of the sodium vapour would have to occur for the lamp to be conducting, if the lamp contents consisted only of sodium vapour, but a "carrier" gas, usually neon, is used in addition to the sodium. This is used at a pressure of several thousand fold that of the vapour pressure of sodium and carries all or the major part of the current. As a result of the ionisation of neon, and other phenomena, many secondary electrons are produced, having energies (approximately 2.5 eq. volts) favourable for the excitation of the sodium D line. The energy dissipated in neon positive ion production appears ultimately largely in the form of heat and raises the lamp to the temperature necessary to provide sodium vapour at the correct pressure.

For a given pressure of vapour, care must be taken not to increase the concentration of excited atoms to an extent that an appreciable number of collisions can occur between them and electrons having energies of three equivalent volts or more, for if this occurs the quantum of radiation desired from the excited atom will not be obtained, but instead a positive ion. The concentration of excited atoms will depend upon the vapour pressure and current passing. With both current and pressure light output does not in-

* The writer is indebted to Mr. C. E. Fenwick of this Laboratory for these.

crease linearly, but shows saturation values. The magnitude of the current to maintain the bulb at the required temperature depends upon the shape of the bulb, and the efficiency of the thermal insulation used. Experiment shows that there is an optimum pressure of sodium vapour corresponding to a temperature of approximately 240° C., and an optimum current beyond which an increase of current can decrease the efficiency to such an extent that the *total* light output falls.

The conditions in a mercury vapour lamp are quite different. As the operating pressure and lamp current increase the efficiency does not suffer, and the colour of the radiation improves. Thermal insulation

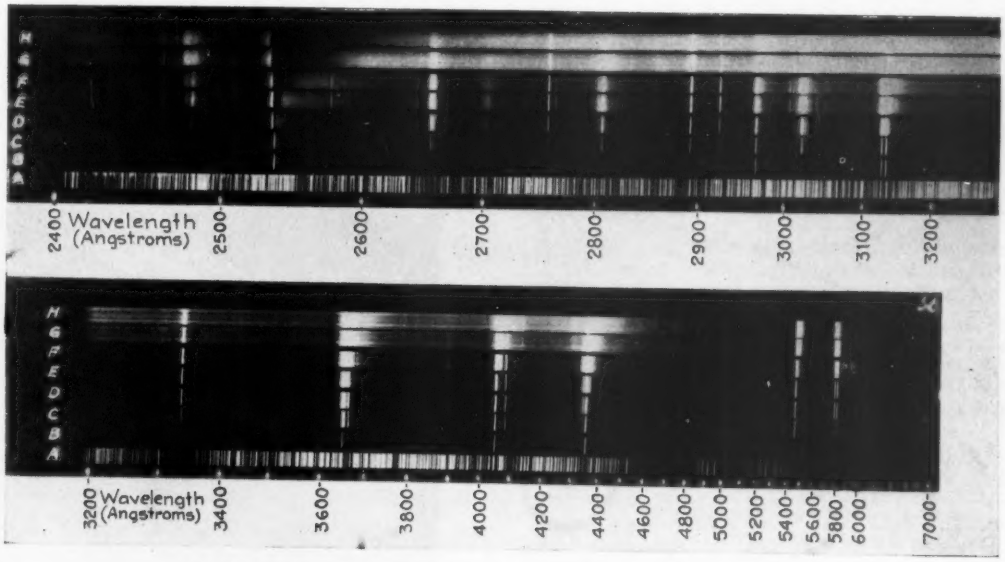

Fig. 5. Spectrum of radiation from discharges in mercury vapour in quartz.

A =	Iron arc for wavelength scale.								
B =	Lamp at	10	v/cm.	0.62	amp.	arc	current	30	sec. exposure.
C =	"	15	"	0.62	"	"	"	10	" "
D =	"	50	"	0.61	"	"	"	7	" "
E =	"	75	"	0.63	"	"	"	5	" "
F =	"	95	"	0.61	"	"	"	5	" "
G =	"	150	"	0.55	"	"	"	4	" "
H =	"	220	"	0.45	"	"	"	3.5	" "

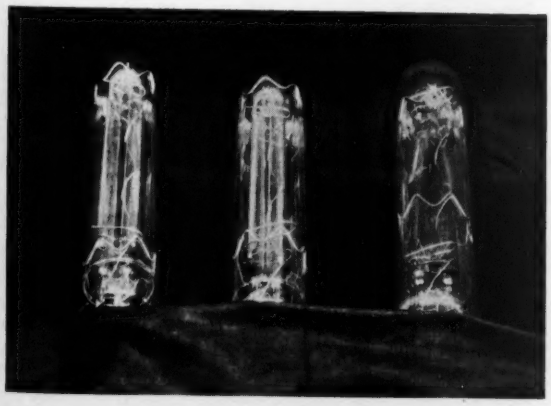

Fig. 6. Hot and cold sodium vapour lamps. Photograph taken in light of tungsten lamp.

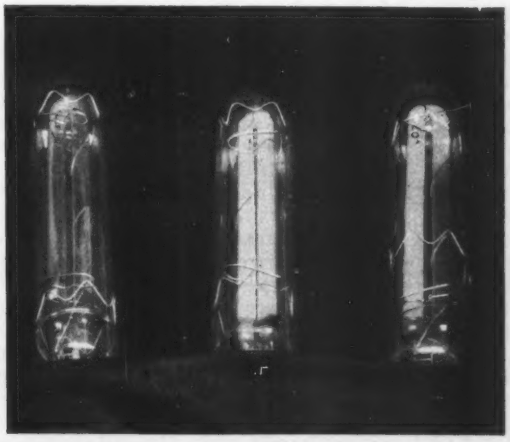

Fig. 7. Re-emission of incident resonance radiation by sodium vapour lamps. The lamp on the left-hand side is cold and the remaining two are hot. The right-hand lamp shows a deficiency of sodium vapour in one limb of the "U" tube. Photograph taken in sodium light.

is thus not so vital, for any decrease in temperature due to poor thermal insulation can be made up by an increase in current through the lamp. The efficiency of light output remains approximately constant.

Indeed the problems in a mercury lamp are not one of careful temperature control, but of heat dissipation and of transparent materials to withstand high temperatures, for to a rough degree of approximation the efficiency increases as the lamp watts per cm. of arc increase. This is shown by the curve in Fig. 8, which is made up from lamps having arc lengths varying from 1 cm. to over 50 cm., and pressures from 0.1 to over 50 atmospheres of mercury vapour.

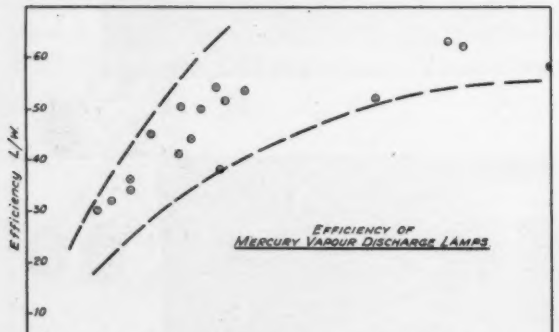

Fig. 8.

This curve is of interest in conjunction with the energy level diagram from mercury. As will be seen, a flat maximum is shown in light output at approximately 100 watts per cm. Above this the efficiency falls slightly but the percentage of red radiation in the light can be made to increase. These changes in efficiency and quality of the radiation will no doubt be completely explained from the energy level diagrams when our knowledge of the various methods of energy transfer are more extensive.

The voltage drop across a lamp varies with the filling gas, both because the nature of the gas, and because the pressure for optimum light output conditions, varies each. As the number of atoms in a lamp increase the greater is the voltage necessary to drive the current through the tube.

Since the conditions of high efficiency allow a high pressure in mercury vapour lamps, the resulting voltage drop per centimetre renders easy a compact lamp for a 200-250 mains circuit having an arc length of 16 cm. for a voltage drop of approximately 150 V. On the other hand the pressure in a sodium lamp is such that the volts per cm. is much lower. We thus find, since the volts per centimetre are inversely proportional to the tube diameter, that sodium lamps are made of narrower tubing than mercury lamps and in much longer lengths, the length being accommodated by bending the tube into U or W shape.

Because of considerations mentioned above, the thermal insulating jackets of sodium lamps are provided by means of separate double walled unsilvered Dewar flasks or else by a number of glass shields inside an exhausted outer containing bulb, whereas the mercury lamp has a simple outer jacket which serves mainly as a shield to the connecting electrodes, and to secure a quick run up to operating temperature. Indeed this jacket need not be exhausted from the efficiency view point.

A further consideration is the way in which the shape of the lamp, necessitated by the above considerations, affects the auxiliary gear required. The starting voltage of a discharge lamp bears but little definite relation to the operating voltage, but depends upon the nature of the gas and cathodes and dimensions of the tube, the wider the tube and the smaller the distance between electrodes the easier the starting. The conditions in the mercury lamp are such that it will start on voltages of 200v. A.C. and the only

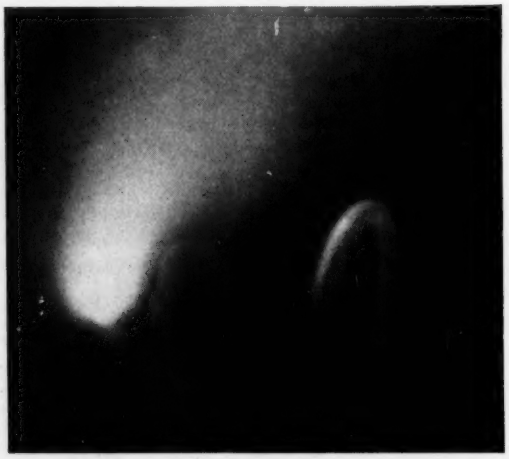

Fig. 9. Enlarged view of H.P. mercury vapour lamp electrode (experimental). Positive half-cycle with electrode acting as cathode.

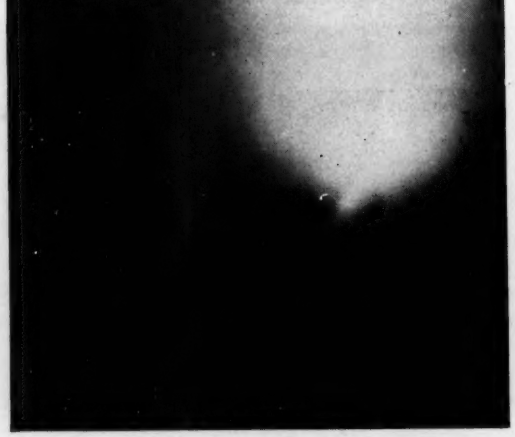

Fig. 10. Enlarged view of H.P. mercury vapour lamp electrode (experimental). Negative half-cycle with electrode acting as anode. Notice position of arc when compared with Fig. 9.

auxiliary gear is a simple choke for stabilisation. The narrow tube of the sodium lamp necessitates a voltage of some 400v., and a transformer is usually fitted to step up the mains to this voltage. In the case of the long positive column lamps it is usual to fit a Tesla coil to ensure reliable starting.

CATHODE DESIGN.

The nature and pressure of the gas affects cathode design, and this must be suited to the lamp. The basic factors affecting the cathode life are those that can destroy its emissive surface, and are:

(a) "poisonous" gases, e.g., oxygen,
(b) temperature evaporation, and
(c) positive ion bombardment.

The first of these is not a difficult problem, and is merely a question of exhaust technique, the second usually occasions no difficulty, for design factors are well appreciated, but positive ion bombardment must always be a problem in discharge lamp design for it is necessary to generate and return ions to the cathode. Owing to the conditions under which bombardment can occur it is more difficult to design a cathode for operation in neon, and the lower the pressure the greater the difficulty. Cathode conditions are easier if the cathode can be maintained at a good emissive temperature, and because, for high efficiency, neon pressures have to be low, for this reason the cathodes of the long positive column neon floodlamps are externally heated, necessitating the fitting of transformers for this purpose.

In the earlier sodium vapour lamps the cathodes were also externally heated, but in later lamps, of the type now made, satisfactory arc heated cathodes are possible In the high pressure mercury lamp the cathodes have always been of the simple arc heated type and are subjected to conditions both favourable and difficult. The arc concentrates on to an extremely small area to an extent that makes the current density taken from this area extremely high. However, the high pressure of vapour is favourable to resist evaporative loss of emissive material, for a high gas pressure surrounding the cathode "plates" back the cathode material.

The design of cathodes for high pressure mercury lamps contains many interesting features, and Mr. H. R. Ruff of this Laboratory has devised and used a method of examination that has enabled us to study cathode behaviour. We allow the cathode to be its own light source and project an image of it through a lens on to a screen. Interposed between the lens and the screen is a disc with a small sector opening, revolved by means of a synchronous motor. If lamp and motor are operated on the same supply it is possible to observe the behaviour of the arc stream and cathode at various portions of the cycle by rotating the motor and disc as a whole.

It is not easy to get good reproduction in photographic form, but Figs. 9 and 10 show the cathode on positive and negative half cycles, and enables the conditions of current concentration and heat dissipation that the cathode has to withstand to be studied.

Before passing to the next section, it should be emphasised that the above paragraphs, which have been included to show the reasons for the various physical dimensions and circuit properties of the electrical discharge lamps at present on the market, treat the subject in the barest outline. While the energy level diagrams are the basis for understanding the processes of light emission the processes occurring in discharge tubes are governed by probability functions. These must be considered before the luminous efficiency arising from any given transition can be estimated.

Application of Discharge lamps.

The present utilisation of discharge lamps covers a wide field, from advertising to medical treatment. The use of the so-called neon or cold cathode tubes of approximately 100 volts per foot, made in various coloured glasses, and using fillings of mercury, neon, helium, or nitrogen is very widespread, but will not be dealt with here. The discharge lamps of the type in which we are mainly interested are in active use for street, industrial, and floodlighting.

STREET LIGHTING.

Some three years ago saw the commencement of new era in street lighting. The first installations, isolated as they were, excited interest as one approached, by reasons of the difference in colour and height of the illuminants compared with installations of older type, and this interest changed to admiration when in the installations, owing to the high degree of visibility that was found. Motorists found that safe driving was possible without the use of head lamps, with an all-round improvement in those factors that make for safe and comfortable road travel. Since these conditions are obtained without the use of increased power consumption, but by increased lamp efficiency, extensions of this method of road lighting were but a matter of time, and to-day there is in this country over 300 miles of discharge lamp street lighting, and there are now installations on the Continent, in America, and in our Colonies.

The requirements of a street lighting discharge lamp may be expressed as follows:—

Efficiency	As high as possible, in general not below 35 lumens per watt.
Colour Rendition and Radiation Spectrum	Not important as long as efficiency is high (with reservations below).
Lumen Output	Between 3,000 and 20,000 lumens.
Starting time	Not important.
Circuit operation	In this country; operation in parallel, mainly on 230V. A.C. Abroad; series operation, mainly at 6.6 A.
Auxiliary gear	Minimum.

With regard to efficiency, the acceptable value must depend on other characteristics of the lamp, and from the economic viewpoint there is a delicate balance between cost of lamp, life of lamp, cost of energy, cost of renewing a lamp, cost of cleaning a lantern, efficiency, cost of lantern and auxiliary gear.

and lantern co-efficient of utilisation, all of which must be considered before it can be said that a particular lamp must have such and such an efficiency for street lighting. But in view of the great necessity for adequate street lighting, not only in restricted areas, as we know street lighting at present, but over great stretches of our main highways, if this is to come to pass as we all earnestly wish, then high lamp efficiency is a basic requirement. In view of the present use of lamps of efficiency of 45 lumens per watt, with some hesitation we place the efficiency for a street lighting lamp at 35 lumens per watt and upwards.

As regards colour, we are accustomed normally to view objects with the full colour radiation of white light, and the absence of any band of wavelengths results in a colour distortion, the extent of which depends upon the width and number of missing bands and the colour of the object viewed. This colour distortion, as has been amply proved, is not important in street lighting. However, it would not be right to consider efficiency regardless of colour rendition. The possibility of making a red lamp highly efficient is remote, but even if available its success might be problematical. The eye under conditions of street lighting is primarily a seeing and distinguishing machine, and not a taster of colours. The present street lighting discharge lamps give their radiation at that part of the spectrum at which the eye is most sensitive and most used to seeing, and under such conditions the eye is apparently completely satisfied.

Lamps Available for Street Lighting.

Two forms of discharge lamps are available for street lighting, and are the high-pressure mercury vapour lamp and certain variations of this; and sodium vapour lamps. Both are characterised by a high efficiency which is, in general, between 40—60 lumens per watt, and a maintenance of high efficiency over lives much longer than those of incandescent filament lamps.

400 *Watt Mercury Vapour Lamps.*—This type, certainly as far as this country is concerned, forms the main street lighting lamp. First manufactured here, it is now made in the chief centres of the world. In this country it is made by various makers to a close degree of standardisation, and there is generally a high degree of unanimity amongst all makers as regards design and size. Typical characteristics are shown in Table II.

TABLE II.

Wattage (200-250 v.)	Overall Length.	Dia.	Light Centre Length.	Average Current.	Typical Lamp Voltage Drop.	Initial Luminous Efficiency.
	mms.	mms.	mms.	V.	A.	lumn/watt
400	325	51	190	3.1	140	45
250	290	51	170	2.0	140	36

Design constants of this type of lamp are now well appreciated, and it is possible to construct this type of lamp over a range of sizes if such are required. In order to secure a good lumen maintenance over the various sizes certain design features are used, which result in an increase of lumen output with increase of wattage. Fig. 11 shows the approximate values of the main properties of this type of lamp, viz., lumens per watt, lamp current, overall length and arc length, as the wattage is varied.

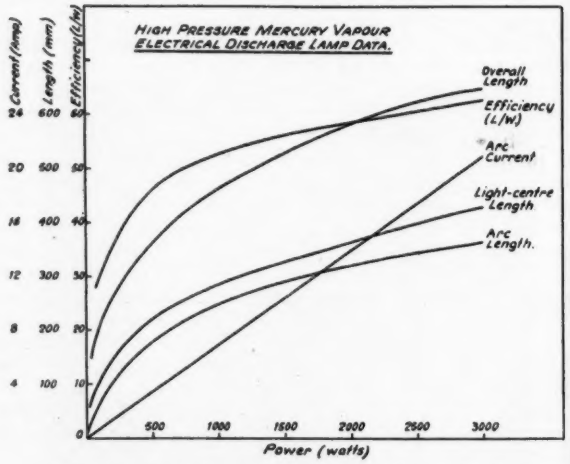

Fig. 11. Approximate values of dimensions, etc., of H.P. mercury vapour.

The 250 watt lamp is the only size other than the 400 watt at present standardised in this country, and its main characteristics are also summarised in Table II.

The lamps are of the type that require only the simplest auxiliary gear, for the cathodes are arc heated, the lamps start on normal mains voltages, and have operating voltages such that they can be stabilised by a compact choke in series with the lamp. A condenser, not necessary for the functioning of the lamp, can be connected across the lamp and choke for improvement of power factor if desired. The actual operating wattage of the lamp is controlled by the impedance of the choke as well as the mains voltage, and to allow for operating the lamp at correct wattage it is necessary to provide an adjustment of the choke. This is done by a series of tappings In manufacture, the size of the lamp and the quantity of mercury is carefully controlled to give the desired lamp voltage drop, which is varied, in order to secure stable operation with favourable power factor, to suit various mains voltages. To cover the range of mains voltages of nominal values 200-250 v., there is thus a range of lamps and a range of chokes, each choke tapped at every five volts. The

table below gives certain figures for the case where a range of three chokes is used covering actual mains voltages of from 185 to 265 v.:—

TYPICAL VALUES FOR 400 WATT CHOKES ON 50 CYCLE SUPPLY.

Choke Type.	Supply Volts.	Cycles.	Approximate Dimensions.			Average Starting Current Amperes.		Average Operating Current Amperes.		Average Operating Power Factor.	
			Width. Inch.	Length. Inch.	Height. Inch.	With capacitance.	Without capacitance.	With capacitance.	Without capacitance.	With capacitance.	Without capacitance.
MR134	185/225	50	5	7	6¾	4.5	5.7	2.7	3.6	0.80	0.58
MR135	205/245	50	5	7	6⅝	4.3	5.7	2.3	3.3	0.82	0.58
MR136	225/265	50	5	7	6⅜	3.8	5.4	2.0	2.8	0.90	0.61

(Capacitance 20 mfds.).
A 1% change in supply volts from the tap volts will give a 3% change in watts and a 4.2% change in lamp lumens.

TYPICAL VALUES FOR 250 WATT CHOKES ON 50 CYCLE SUPPLY.

Choke Type.	Supply Volts.	Cycles.	Dimension.	Average Starting Current Amperes.		Average Operating Current Amperes.		Average Operating Power Factor.	
				With capacitance.	Without capacitance.	With capacitance.	Without capacitance.	With capacitance.	Without capacitance.
MR141	185/225	50	Overall Dimensions are similar to those for 400 watts.	3–4	4–5	1.5	2.2	0.8	0.59
MR142	205/245	50		3–4	4–5	1.45	2.1	0.84	0.58
MR143	225/265	50		3–4	4–5	1.3	1.9	0.90	0.61

(Capacitance 15 mfds.)
A 1% change in supply volts from the tap volts will give a 3% change in watts and a 4.2% change in lamp lumens.

In most installations the choke should first be set to an approximate tapping, and the actual voltage measured along the installation with lamps operating, and the final adjustment made by altering the tapping to the actual measured value. This adjustment need only be altered if there is a change of supply voltage. There is no need, of course, to adjust for lamp renewals.

For street lighting, many special lanterns have been developed for the high pressure mercury vapour lamp, and most installations follow modern principles in which the lantern is mounted high with a good overhang on to the road. Fig. 12 shows dimensions and form of a typical modern pole unit for lamps of this type. A feature of note is the use, in some cases, of the lamp mounted horizontally. This will be treated under "Floodlighting."

The Sodium Vapour Lamp.—The Sodium Vapour Lamp is the only other type of lamp, using a basically different gas, available for street lighting, and it therefore results in the position that at a comparatively early stage in the utilisation of discharge lamps the lighting engineer has available two distinct types of lamps for the same purpose. It is not proposed in this paper to pass judgment on their relative merits, but only to mention certain salient points. There are more diverse types in sodium lamps than in mercury vapour lamps, the former have been utilised mainly on the Continent and in America rather than in this country.

In connection with the utilisation of sodium lamps for street lighting, perhaps the most significant feature to note is that the increased bulk of sodium lamps for a given wattage favours the use of units of small lumen output, and that the large size of the light source renders difficult the close control of the light flux. This leads to a comparison of the general type of installation that results from using the lamps rather than of the lamps themselves, which are not

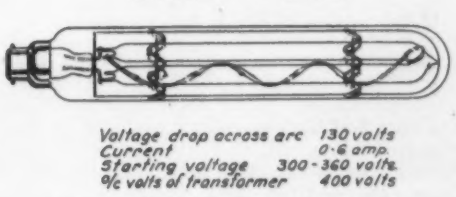
POSITIVE COLUMN SODIUM VAPOUR LAMP.
RATING 70 WATTS
Length overall 315 mm.
Diameter 61 mm.
Voltage drop across arc 130 volts
Current 0·6 amp.
Starting voltage 300-360 volts
% volts of transformer 400 volts

Fig. 11a. Typical sodium vapour lamp.

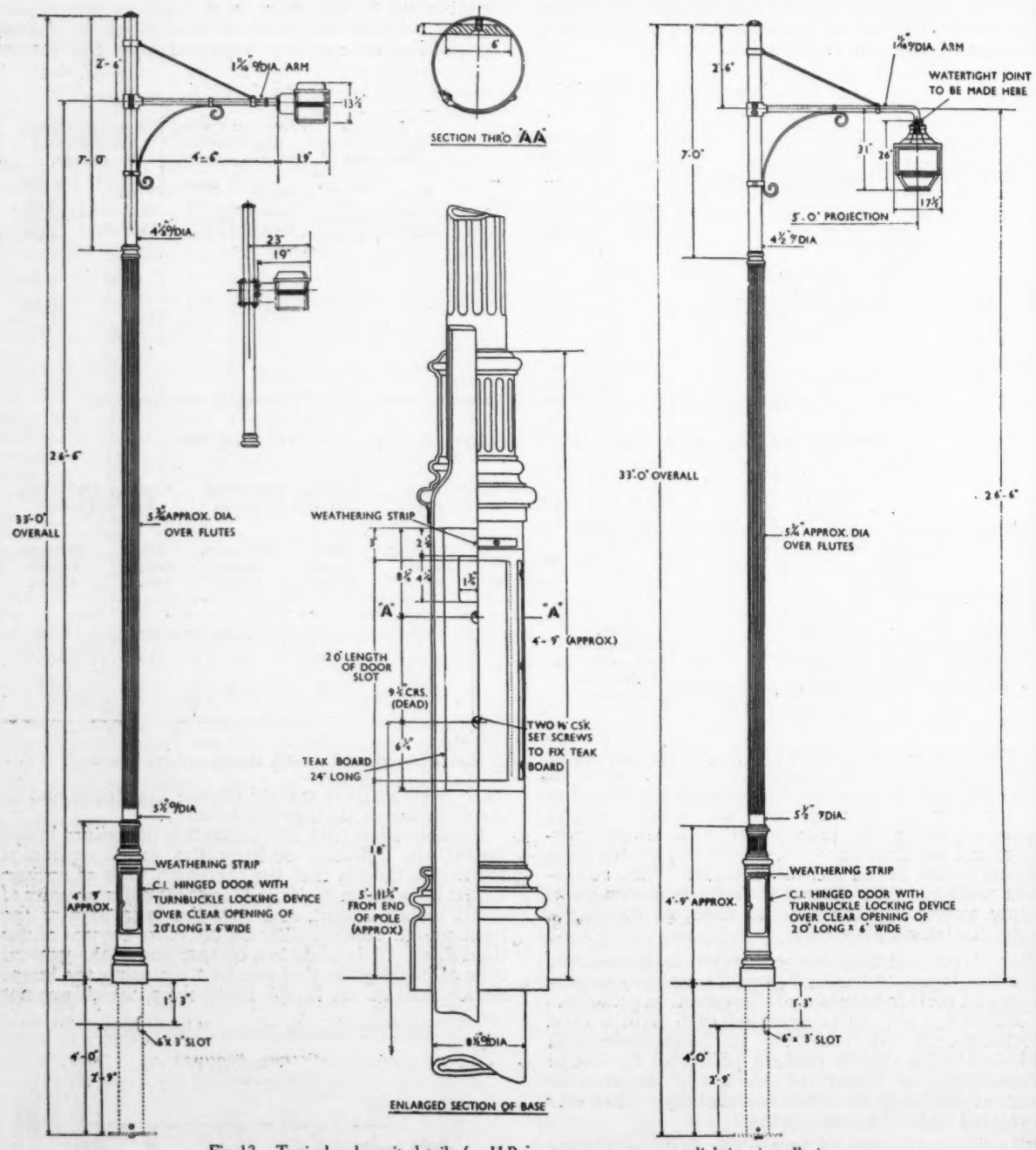
SECTION THRO' AA
WATERTIGHT JOINT TO BE MADE HERE
5'-0" PROJECTION
33'-0" OVERALL
26'-6"
WEATHERING STRIP
C.I. HINGED DOOR WITH TURNBUCKLE LOCKING DEVICE OVER CLEAR OPENING OF 20" LONG x 6" WIDE
TWO ⅜" CSK SET SCREWS TO FIX TEAK BOARD
TEAK BOARD 24" LONG
20" LENGTH OF DOOR SLOT
ENLARGED SECTION OF BASE

Fig 12. Typical pole unit details for H.P. mercury vapour street lighting installations.

directly comparable. The high lumen output mercury unit used at distances of from 120-175 feet with its comparatively small size arc enables the light to be directed accurately to secure high background brightness. The sodium lamp for equal total lumens on to the road has the units spaced closer along the road and sometimes uses "hooded" lanterns and gives a different form of lighting. It is hardly necessary to mention that in the sodium lamp installations colours disappear and appear as yellows of different brightnesses. In the mercury lamp installations, brick, stonework, and road surfaces, hedges and trees, are

all differentiated by colour as well as brightness. The writer has seen excellent installations using both forms of lamps, and both forms of installations have their supporters, and are being tried out in this country.

Industrial Lighting.

After street lighting the most prominent use for discharge lamps is the lighting of industrial sites, e.g., workshops, assembly bays, factory yards, collieries, cement works, omnibus depots, garage filling stations, etc. In short, any industrial situation in which two characteristic features of the discharge lamp do not clash with peculiar conditions of the particular factory. We refer here to the colour of the light radiated and the instantaneous values of the light output over the alternating current cycle. Owing to the selective radiation of the discharge lamp accurate colour matching is not possible, but this is a requirement of but a few specialised industries, and is a problem of difficulty with any illuminant, necessitating special filters, etc., resulting in low efficiency.

The light source of the discharge lamp has no thermal capacity as has a filament, and consequently the light output follows closely in shape the wave form of the current supply, and in a factory with unguarded machinery, synchronised with the lighting supply, might give stroboscopic effects considered undesirable. These effects, however, are not nearly so marked as is sometimes supposed, and cases of unguarded machinery revolving at correct speeds are comparatively rare. The two characteristics mentioned do not constitute practical restrictions of any great value, and the use of discharge lamps in industrial situations is making great advances.

The type of lamp used is generally the mercury vapour type in either the 400 or 250 watt size, and needs no description peculiar to this use. The high efficiency of this form of lamp encourages its use as part of a general tendency to better lighting, and also forms a very attractive feature when the conversion of existing installations to obtain better lighting at the minimum expense is considered. A word of caution might be interposed here. The mercury vapour discharge lamp can often be used to advantage in existing fittings and lanterns, but the resulting light distribution should be carefully checked owing to the linear nature of the light source as compared with a tungsten filament lamp.

It should be noted that the quality of the radiation of the mercury vapour lamp seems to make it peculiarly suited to a number of industrial situations. There is sufficient colour range to allow of the distinguishing of colours, but the increased concentration of light into the green and yellow wavelengths seems to have the property of throwing into prominence surface films of dirt and other surface defects. In our experience, whenever a change to high pressure mercury lighting has been made the operators who have to work in the light have expressed approval at the change, and while some of this has been due to the increased quantity of foot-candles on the job there are frequently advantages noticeable due to the colour quality of the radiation. Examples of this are met with in the examination of sheets of metal, in coal sorting, bus cleaning, casting in foundries, etc.

It is of interest to note that the use of high pressure mercury vapour lighting is making rapid advances in America, although initiated later there than in this country, and the two photographs Figs. 13 and 14, produced here through the courtesy of Dr. Mailey, of Hoboken, N.J., may be of interest.

Fig. 13. Use of H.P. mercury vapour lamps in industrial lighting in U.S.A.

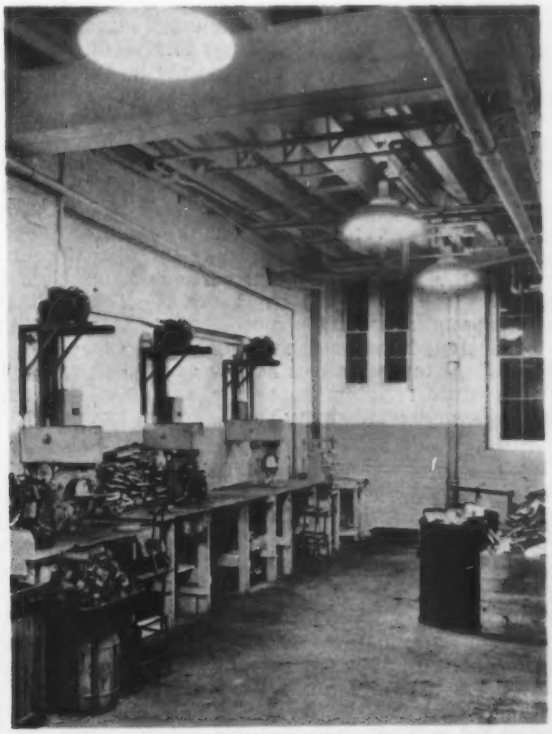

Fig. 14. Example of lighting of punch press shop with H.P. mercury vapour lamps in U.S.A. Average light intensity 40 ft. candles.

Two discharge lamp installations, one of sodium lamps and the other of mercury lamps are in use in the B.T.H. Research Laboratories, and have proved very successful, and discharge lamp installations are used extensively in these works.

A type of lamp of interest for general use is the 100-130 volt high pressure mercury vapour lamp, and since there are quite a number of factories on this voltage range it is mentioned under this heading, although it is equally suitable for street-lighting.

While the use of the third wire starting method brought about reliable starting down to 200 volt mains, from the original value of 230-250 volts, and while lamps of the normal type can be made so that they will start on voltages of, say 140 volts, without some new method it was not possible to make this type of lamp so that it was reliable as regards starting, in all weathers, on the low voltage circuits.

For a discharge to pass into an arc it is necessary for the cathode to emit a copious supply of electrons. On high voltages, positive ionisation takes place to such an extent that the energy given up by the positive ions to the cathode as they fall into it is sufficient to raise the cathode temperature to a sufficient extent to enable electrons from it to take part in the discharge and secure the desired arc-like characteristics.

To secure this happening on low voltages it is necessary to provide initial cathode heating and the problem was mainly one of how to do this without complicating the circuit and amount of auxiliary gear required. It was found sufficient to give initial heating to one cathode only, and the method devised in our laboratories was to use a simple switch of thermostatic metal connected in such a way inside the outer jacket of the lamp that on switching on, current is passed from the mains, through the choke and through one cathode. As this reaches a dull red heat, and from 40-50 seconds only is required, the heat conducted to the thermostatic switch is sufficient to open this and allow the current to take its normal course through the choke and from cathode to cathode in the lamp, the lamp then operating as a normal mercury vapour lamp. This method has enabled lamps to be designed that will start on voltages as low as 70v. A.C. at temperatures as low as —20°C, and has proved quite reliable in service, lamps on life test having been started many thousands of times.

Flood Lighting.

Flood lighting is mainly required for spectacular purposes and the discontinuous nature of the radiation of the discharge lamp makes this lamp particularly suitable for this application, for by its use effective colours at high luminous efficiency can be obtained.

For this application two lamps previously dealt with, the high pressure mercury vapour lamp and the sodium vapour lamp, are used, and in addition a further type has been developed, viz., the externally heated hot cathode, long positive column lamp, with fillings of neon for red flood lighting and of "low pressure" mercury vapour for flood lighting in certain colours obtainable by the use of coloured glasses. In this application, once again the high pressure mercury vapour lamp is found of very general utility.

Dealing first with the neon and low pressure mercury long positive column lamps, these are made in wattages of between 200 and 400 watts, and overall lengths of 33 to 46 in., the variation here being due to the practice of various makers and the colour required. Losses in the auxiliary gear increase the overall watts by some 12 to 18 per cent. This gear consists of filament heating transformers, series choke, and Tesla starting coil. The circuit is usually arranged so that a reduced voltage is placed on the filament heating transformers and Tesla coil primary as soon as the tube passes current.

The lamps, in practice, are mounted horizontally in reflectors designed to give an even dispersion of light on a vertical surface placed adjacent, and usually, above the flood lighting lamp. The linear light source of the discharge lamp makes a horizontal mounting necessary for best lantern utilisation in many applications, and this position occasions no difficulty in low pressure lamps, but in high pressure lamps the high temperature of the arc and the strong convection currents set up thereby sweep the arc upward if a lamp is placed in the horizontal position. This movement of the arc brings about a decrease of efficiency of over 11 per cent., and seriously reduces the reliability and maintenance during life of the light output of the lamp. Since, however, the arc is a flexible conductor carrying a current it can be moved by a magnetic field, and this principle is used in certain lanterns both for street lighting and for flood lighting. The control electro magnets occupy a small volume, and are connected permanently across the lamp cap terminals in the lantern, and since the magnet is preset during the fabrication of the lantern to take any lamp its presence causes no difficulty to the user.

In use, the high pressure mercury vapour lamp enables many beautiful flood lighting effects to be obtained. Its "straight" or full colour radiation suits many types of stone and brick surfaces (the County Hall, London, is flood lighted with these lamps) and is particularly satisfying on historic buildings of grey weathered stones. By the use of filters placed in front of the lantern the various colours present in the mercury vapour discharge can be separated and obtained at will at high efficiency without changing the lamp. Of course, red is absent and if this colour is desired it must be obtained by the use of neon.

The following table gives some of the colours available with the respective efficiencies, obtainable by the use of various types of discharge lamps, together with the efficiencies obtained by the use of incandescent lamps plus filters. The superior efficiency of the discharge lamps together with the superior utilisation for flood lighting of the linear light source placed horizontally make it evident that there is a big field for this type of illuminant in this application.

Efficiencies of Electrical Discharge Flood Lighting Lamps.*

(Overall Efficiencies are given, including any losses in auxiliary gear.)

Colour of Light.	Lamp.	Efficiency. l.p.w.
Light blue	L.P. Mercury	12.0
Very light violet	H.P. „	26.0
Light blue	H.P. „	11.0
Med.	H.P. „	7.0
Light green	L.P. „	12.0
Dark green	L.P. „	9.0
Very pale green	H.P. „ (Used without filter)	42.5
Light green	H.P. Mercury	13.0
Med. green	H.P. „	10.0
Yellow	Sodium	38—45
Yellow green	H.P. Mercury	16—28
Pale yellow	H.P. „	18.5
Red	Neon	9.5

(For the above colours the efficiency of tungsten lamps plus filters is from 3 to 8 l.p.w.)

MISCELLANEOUS USES.

There are a number of miscellaneous uses of discharge lamps which need be mentioned but briefly here. They serve perhaps to indicate that as the number of types of discharge lamps increases, more and more uses will be found.

Industrial and Medical.—Ultra-violet light of high efficiency is obtained from the mercury vapour discharge, and has uses in industry and in the medical field. An interesting lamp of certain uses may be mentioned here particularly because it is the one type of discharge lamp that has been used in the home. This is a form of lamp, in which, in a bulb of special U.V. transmitting glass is mounted a filament in mercury vapour. The filament voltage and shape is so arranged that when the filament is incandescent an arc in mercury vapour operates in parallel with it, and the lamp thus gives a pleasing mixture of visible light plus ultra violet radiation.

Scientific and Industrial.—The monochromatic nature of the light from certain discharge lamps, particularly sodium, makes it useful for certain scientific measurements. The actinic value (for certain plates and most bromide papers) of the light from the high-pressure mercury vapour lamp is high, and likely to be made use of in photographic processes. Standard mercury lamps are already in use by some industrial firms for enlarging and copying. The table below shows the relative efficiency for various photographic materials of HP mercury vapour and tungsten light.

Recent Advances in Design and Technique.

During the three or four years that have elapsed since the introduction of the modern practical discharge lamps there have been many detail improvements, mainly due to the increased control over manufacturing processes as the production of the lamps has been taken over by the various lamp works. There may be mentioned here in connection with the high-pressure mecury vapour lamp, improvements in initial efficiency and in maintenance of light throughout life.

STOCK		EMULSION	Speed to Mercury / Speed to Tungsten — Tungsten Temperature 2900° Equal Light	2900° Equal Power	3200° Equal Power
Negative	A	Hypersens. Pan.	.8	2.0	1.4
„	B	Spec. Rapid Pan.	.8	2.0	1.4
„	C	Commercial Ortho	1.8	4.5	2.8
„	D	Supersens Ve Pan.	.9	2.2	1.6
„	E	Ordinary Pan.	.9	2.2	1.6
„	F	Ortho	1.6	4.0	2.5
Positive	G	Film Stock	2.4	6.0	
„	H	Bromide	2.3	5.8	
„	J	Gaslight	2.2	5.5	
„	K	Gaslight	2.6	6.5	

When first introduced the initial efficiency of the 400 watt lamp was approximately 40 l.p.w.; it is now definitely 45 l.p.w., an increase of 11.2 per cent. The word "definitely" is used here, because when these lamps were first introduced one could not be quite sure that a "mercury" lumen was equal to an "ordinary" lumen owing to the large colour difference. This has now been cleared up and the photometry of these lamps put on a firm basis. The maintenance of lumens throughout life has also improved, until it now compares closely with the standard tungsten filament lamp. In this connection, of course, the vastly superior efficiency of the discharge lamp must be remembered.

Modifications of the standard mercury lamp have been made and include the 100-130 volt lamp, and the horizontally used lamp already mentioned, and in addition use has been made of other components such as cadmium, the latter in order to impart a certain percentage of the red light normally lacking in the mercury discharge. To this same end, mercury discharge lamps have been run in combination with tungsten filament lamps, and recently a lamp has been made in which the tungsten filament is placed in the same outer-containing bulb as the mercury discharge lamp. In this lamp the tungsten filament is also used to stabilise the arc.

The efficiency of these colour modified lamps is naturally less than that of the straight mercury lamp,

* The figures in the above table for L.P. Mercury and Neon are quoted from a paper by R. O. Ackerley, G.E.C Journal, Nov., 1934, and those for the H.P. mercury are due to Mr. H. R. Ruff, of the B.T.H. Research Laboratory.

the two examples mentioned having respectively efficiencies of approximately 82 and 60 per cent. of the standard 400-watt mercury lamp.

The data given in the earlier part of the paper indicates that our general knowledge of the discharge lamp is increasing, and this is likely to be reflected in the practical lamps available in the next few years. Three items of recent work have been selected as of interest for this paper, but will be indicated mainly as experimental demonstrations.

(1) Extra High-Pressure Lamps.

It has long been recognised, although quantitative data has been lacking until recently, that the efficiency and colour content of the light output of the mercury vapour discharge could be improved by increasing the operating pressure. Indeed, the standard 400 watt lamp is an example

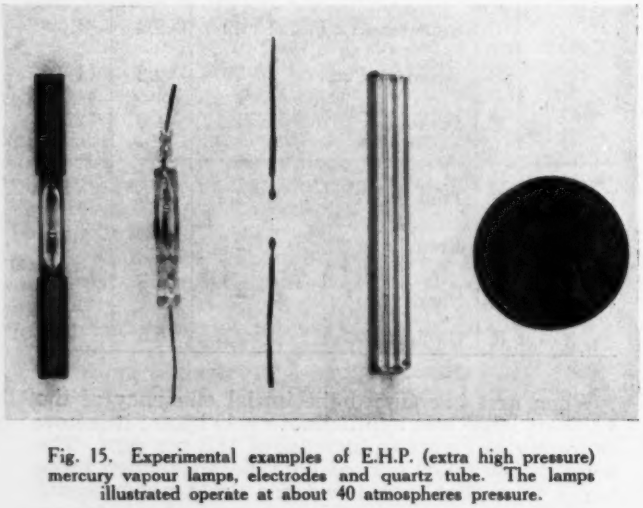

Fig. 15. Experimental examples of E.H.P. (extra high pressure) mercury vapour lamps, electrodes and quartz tube. The lamps illustrated operate at about 40 atmospheres pressure.

of this. Any large increase of operating pressure, however, necessitates an increase of operating temperature, and the problem thus becomes one of finding material that is transparent and which does not soften or suffer chemical attack at, say, temperatures of from 700 to 1000° C. Such a material is quartz, and it has in addition the property of a very low-temperature coefficient of expansion that enables it to withstand the differences of temperatures that its use in such lamps entails. This property, however, combined with its high melting point renders it a very difficult material through which to pass vacuum-tight leads of the usual high temperature glass-sealing metals, viz., tungsten or molybdenum.

Special glasses have long been known with varying coefficients of expansion, the use of a graded series of which will enable seals to be made between glasses of quite different expansion, e.g., soda and borosilicate glass, and such seals can be used for quartz. However, it is always necessary in designing a high pressure mercury vapour lamp to ensure that the total length of the lamp proper (not of the outer jacket when one is used) is but little longer than the arc length, and this requires that the seals be as compact as possible. The reason for this is to avoid pockets in which mercury vapour can condense and to avoid extremes of temperature between the centre and ends of the lamp.

This condition has been met by the development of a special glass that will seal to quartz and also to tungsten. Lamps using this have been studied by Messrs. Philips of Einhoven, Holland.

In the laboratory with which the writer is connected a totally different method has been used (and in this connection we acknowledge gratefully the help received from our friends in the Research Laboratory of the G.E.Co., Schenectady, U.S.A.), and lamps have been constructed in which a metal (molybdenum) is sealed directly into quartz without the use of any intermediate glass. The photograph in Fig. 15 illustrates the lamp and seal and component parts.

Having a method of manipulating metal and quartz so that a lamp of the desired shape and material can be made, what are the characteristics and advantages found when the arc in mercury is operated at extremely high pressures? They are at least fourfold.

(1) For a given watts input the overall size of the lamp is small.
(2) The efficiency is increased as the operating pressure is increased.
(3) The colour content of the radiation improves as the pressure is increased.
(4) The intrinsic brilliancy of the arc increases as the pressure is increased.

A further point to note is that the use of quartz permits of extreme temperature differences between its inner and outer surfaces and enables a lamp made of quartz to be operated at extremely high loadings with water cooling.

The small lamp illustrated is an experimental form only, and has the following dimensions:—

Overall length of quartz	40-50	mms.
Overall diameter	6.5	„
Arc length	10	„
Internal diameter (approx.)	2.5	„

Such lamps operate at 70 watts at pressures giving voltage gradients of from 150 to 300 volts per cm. The luminous efficiency is between 50 and 60 l.p.w., and the colour is modified by the high pressure to an extent that it includes up to "4 per cent. red."

A spectrogram of such lamps at various pressures has been given in an earlier part of this paper (Fig. 6).

This extra pressure lamp is likely to be of great technical interest although at present it is not yet in a stage in which it can be utilised commercially. Its small size, high efficiency, and high intrinsic brilliancy are attractive for many applications, of which optical projection appears to be an important one.

Many more general applications, such as street lighting and industrial lighting, demand a simplicity and high degree of reliability and maintenance of luminous output together with a high efficiency, and these factors are combined to a high degree in the standard 400-watt mercury lamp, which is not likely

to be supplanted, for the applications for which it has been developed, for some considerable time.

Use of Fluorescent Powders.

An early experiment in discharge tubes was to observe the beautiful colours and light emission that could be obtained when certain minerals were exposed to electron bombardment. The same effect can be observed in modern cathode ray tubes. Of more interest in lamp technique is the utilisation of certain luminescent powders under the influence of ultra-violet light.

One of the commonest of fluorescent powders is Willemite or zinc silicate, and if this is exposed to the light from a mercury vapour lamp through a screen of special glass that absorbs the visible light but passes ultra violet it will be observed that the Willemite fluoresces brightly.

The possibility of ultra violet light emission is likely from many of the gases used in discharge lamps, and while the lamps have been designed to suppress as much as possible unwanted invisible radiation, complete suppression is not possible. The use of luminescent powders suggests that an increase of efficiency should be possible since they have the property of acting as frequency changers, converting invisible radiation into visible light, with a gain in efficiency. The increase in efficiency will depend upon the proportion of U.V. radiation in the original discharge, and will be high, for example, in a low pressure mercury vapour lamp which has a strong radiation at 2,537Å. A ten to twenty-fold increase of efficiency can be obtained using Willemite. This remarkable increase in efficiency, obtained merely by putting a layer of zinc silicate on the inner wall of the discharge tube, is due mainly to the large amount of arc energy that is radiated by very low pressure lamps at 2,537Å and to the fact that the radiation given off by the excited Willemite is in the green region to which the eye is sensitive

The problem of applying fluorescent materials to the high pressure mercury vapour discharge lamp to obtain increased efficiency and/or improved colour radiation is more difficult. Many possible fluorescent powders are being made up and examined and give a variety of fluorescent radiations from "white" yellow, yellowish red, to deep red, and a number will be demonstrated.

Special Lamps for the Examination of Moving Machinery.

This has been selected as an example showing how the special properties of the electric discharge can be utilised in lamps designed for certain specialised purposes. The luminous electrical discharge has no time lag such as is possessed by other light sources, and it can be stopped and started virtually instantaneously. It is possible to design a discharge lamp somewhat similar to a "Thyratron" (indeed a "Thyratron" is a hot cathode mercury vapour discharge "lamp" in the sense that it gives out some light), and thus enables the discharge to be started by a small impulse, and have an extinction voltage almost equal to its striking voltage; this means that if the energy for the discharge is obtained from a charged condenser, even though this be of large capacity, the duration of the flash will exist for a very short time only. A circuit can be arranged so that the condenser can be periodically recharged, and if the condenser is large and the discharge tube suitably designed a series of flashes of high brilliancy and very short duration will be obtained. An apparatus of this kind is of great value for examining moving machinery. Using a hot cathode mercury vapour lamp and a 60 microfarad condenser charged to a peak voltage of about 150v., the duration of each flash of light is less than 1/20,000 of one second. The intensity is high enough to allow the lamp to be used in any normal room in dull daylight.

The apparatus will be demonstrated in operation.

Conclusion.

In conclusion I should like to express my thanks to my colleagues in the Research Laboratory at Rugby, without whose help this paper would not have been possible, and especially to Mr. H. R. Ruff. and also to Mr. Hamilton and Mr. Rule., of the B.T.H. Co.'s Lamp Works. I would also like to take this opportunity of expressing my appreciation of the many helpful conversations I have had with Dr. Found and Dr. Mailey and others of the G.E. Co., Schenectady, U.S.A.

I record grateful thanks for permission to publish this paper to Mr. Warren, Chief of the Research Laboratory. and to the Directors of the British Thomson-Houston Co., Ltd., Rugby.

DISCUSSION

Mr. J. W. Ryde, after congratulating the author on his excellent demonstrations, first referred to the remark in the paper that, in the case of the sodium lamp, the light came only from a layer of vapour immediately next the inner surface of the lamp bulb. Whilst, in general, he agreed with this, he did not think the effect was quite so much as had been indicated. He believed that some of the sodium light passed right through the tube and, therefore, in actual practice, light was obtained to some extent throughout the volume of the tube, at any rate, in the case of a tube 1 cm. diameter. If dark glasses are worn, a small reflecting surface can be seen, and its shape clearly distinguished, through about 1 cm. of the excited sodium vapour.

Mention was made in the paper of the favourable effect of high pressure in reducing the losses of emissive material of the electrode, but he would like to know why the author thought there would be less loss at high pressures due to the sputtered

atoms of the cathode material being charged. Had the author also studied the cathode fall at pressures much above one atmosphere? From some provisional work done in the G.E.C. laboratories there was an indication that, starting at low pressures, the cathode fall increased as the pressure increased.

The reference to cold cathode tubes of approximately 1,000 volts per foot seemed to be a misprint, as the standard for 20 mm. advertising neon tubes was about 100 volts and for mercury tubes 70 volts per foot.

It was stated in the paper that in the case of industrial lighting, owing to the selective radiation of the discharge lamp, accurate colour matching was not possible, but he imagined this referred to sodium and mercury lamps because it was possible to get extremely good colour matching with a suitably designed carbon dioxide tube.

Referring to fluorescent powders, Mr. Ryde said that his colleagues, Mr. Randall and Mr. Jenkins, had been studying this matter for some time both from the point of view of the preparation of special compounds and also their application to all kinds of discharge tubes. One of the simplest materials, as pointed out in the paper, was synthetic Willemite —the spelling was not Wilhemite, as used in the paper. (This material was recognised as a distinct mineral in 1830 and it was named after Willem, King of the Netherlands, and not after Wilhelm, the German Emperor!) The fluorescence of this material was due to the presence of small quantities of impurities, notably manganese, but the efficiency of the fluorescence depended very considerably on the method of preparation. One difficulty was that the lumen maintenance of the material, when put into the tubes, was not very good, but work in the G.E.C. laboratories had resulted in a certain improvement in that direction, and recently they have been able to produce powders which would fluoresce under neon radiation without any mercury present whatever, and in these circumstances the maintenance was very much improved. The trouble seemed to be that a thin film of mercury and possibly of something from the electrodes settles on the powder and absorbs the radiation. Considerable study had also been given to red fluorescent powders applied to the high pressure mercury vapour lamp, and they had succeeded in making up for the deficiency of the red to a very considerable extent.

Mr. C. R. Bicknell, referring to the classification of "Medical and Special Uses" in Table I. for Combination and Miscellaneous Lamps suggested that one combination lamp, the "dual," was of general use, and should have come under a heading, "General Uses." Commenting on the statement in the paper that "In the case of the long positive column lamps it is usual to fit a Tesla coil to ensure reliable starting," Mr. Bicknell recalled that at the opening meeting of the Society this session a 24-inch column lamp was shown that starts up without the use of a Tesla coil. Later in the paper reference was made to choke coil adjustment, it being stated that "This is done by a series of tappings." Whilst agreeing that this was the most commonly used method, he remarked that there was at least one system on the market in which impedance variation is performed by adjustment of the air gap.

With regard to the efficiencies of those lamps referred to by the author as "colour modified," and for which he gave efficiencies of approximately 82 per cent. and 60 per cent. of the standard 400-watt high pressure mercury lamp, the former figure for the lamp, in which the colour modification was obtained by the mixture of gases and vapour in the inner tube, was a direct comparison of lamps operating under similar conditions, and therefore quite straightforward. It seemed, however, that in comparing the dual lamp with the 400-watt mercury lamp on a percentage basis without further explanation, the author had been a little unfair in opening the ledger and showing only the debit side. This debit side shows the 40 per cent. lower efficiency of the dual lamp overall, including the tungsten filament, but what of the credit side? Here it was found that no choke was required, and as the choke was the criminal that upsets the power factor, the elimination of the choke automatically eliminated the condenser. The fact of no choke or condenser being required introduced a further item which appears on this side of the ledger, viz., the saving in capital cost of the means of housing them, whether this be in the form of a special box or accommodation in the base of a column. In these days of progress and rapid advance in the scientific development of electric discharge lamps, the question must arise as to whether users should not review the period usually allowed for the writing-off of plant and considerably reduce it; in which case the saving in capital cost referred to above would become still more important than it was at the present customary rates of depreciation.

In the course of his lecture, but not in the proof of his paper, the author had mentioned horizontal lamps for floodlighting, and said that this entailed the use of magnetic control of the discharge; but in saying this he had apparently overlooked one make of horizontal discharge tube that would operate without any magnetic control.

In conclusion Mr. Bicknell asked the author to explain why, in the stroboscopic experiment shown, in which red and green light was directed on to a revolving disc, the background remained white.

Mr. W. J. Scott pointed out that in the incandescent lamp there was a certain amount of waste radiation which was virtually all in the heat end of the spectrum and it was not possible to transform this into visible radiation by the use of ordinary luminescent substances. On the other hand, in the case of the electric discharge lamp there were usually a number of lines in the ultra-violet end of the spectrum which emitted a large portion of the total radiated energy. As a rule these could be transformed into light by means of appropriate luminescent substances. That was what the author had been demonstrating. He had been getting "something for nothing." Another point was that if a ceiling or a room or any object was covered with luminescent powder and ultra-

violet light was directed upon it, there was virtually no specular reflection. Each little grain of powder acted as its own light source. The stroboscopic lamp would interest mechanical engineers. It worked directly off low voltage supplies, as low as 110 volts if necessary, and it was the particular properties of the tube, inherent in its design, which made the accurately controlled and sharp definition possible.

Mr. W. RULE said his chief interest was in the manufacture of the lamps. He had been, therefore, particularly interested in the lecturer's demonstration making use of the stroboscopic effect to show that in the running of a lamp the tungsten spiral and the thermionic material acted respectively as anode and cathode. The relative juxtaposition of these two elements was, therefore, of great importance in that it played a determining part in the lumen maintenance of the lamp. If the thermionic material was too far recessed in the spiral the tungsten tended to act both as anode and cathode. If, on the other hand, it projected beyond the end of the spiral, the thermionic material tended to act both as anode and cathode. Both these conditions led to decreased lumen maintenance and it was, therefore, necessary to have the spiral and thermionic material so situated with regard to each other that they always functioned as anode and cathode respectively.

With regard to modification of colour distribution it should not be forgotten that while the discharge was improved by the addition of red, tungsten radiation was also improved by the blues and greens which the discharge introduced. The colour distribution of the combination was, therefore, superior to either of the sources used separately.

Mr. J. S. Dow remarked that the applications of fluorescence really came into the subject of the next meeting of the Society, but there was only one issue he wished to mention. The author had illustrated lamps in which it was shown to be possible, by introducing fluorescent powders, to extend the range of colours, and he could also understand that if one had a tube containing practically no visible light but mainly ultra-violet light, it was possible to increase its luminous efficiency by introducing fluorescent material. Was it possible, however, with that form of energy in conjunction with fluorescence, to get an efficiency in any way comparable with that obtained with a mercury or sodium discharge lamp, or was the efficiency necessarily very much less? Again, in the case of a mercury or a sodium lamp which emitted a considerable amount of visible light, but also a great deal of non-visible energy was it possible by introducing fluorescent material which was excited by the ultra-violet energy to get a gain in total efficiency? One would imagine that although using a fluorescent powder to convert the non-luminous energy into luminous rays constituted a gain, much of the existing visible light might be obscured, with the result that the total gain might be of little value.

Mr. L. J. DAVIES, replying to the discussion, first of all thanked the various speakers for their interesting comments and for calling his attention to certain typographical errors in the printed proof of the paper. These would be corrected.

With regard to Mr. Ryde's point concerning the absorption of sodium light by the sodium vapour within the lamp, the magnitude of such absorption, and the extent to which light issued only from a layer of vapour immediately next to the inner surface of the lamp, depended upon the design of the lamp. With large diameter lamps, e.g., approximately 6 cm. in diameter, taking an arc current of some 6 amperes it was very largely true to say that the bulk of the light emission was a surface phenomena

The prevention of loss of emissive material from a cathode by the use of a surrounding gas atmosphere at high pressure was an experimentally demonstrable phenomenon; a large part of the effect was probably due to mere obstruction by the surrounding gas atoms. Some fraction of the particles evaporated or sputtered from the cathodes were charged, and this fact influenced the loss of emissive material and the ultimate destination of the material lost. The paper should not be read to imply that there would be less loss due to charged particles at high pressure. Arcs had been studied by the author and his colleagues up to and above 60 atmosphere pressures, and while the cathode face had not been studied in detail there was no evidence of a very pronounced increase in cathode fall.

The author agreed that the carbon dioxide tube gave an extremely good colour match, but this type of lamp had not been considered as a practicable source for general industrial lighting owing to its low efficiency of 2.3 lumens per watt.

Mr. Ryde's remarks on fluorescent and luminescent powders was of interest and emphasised the importance of this material in discharge lamp work. The author can confirm that the efficiency of such powders depends upon the method of production and that powders can be made giving a fair degree of red correction and having a reasonable maintenance of properties during life.

The point raised by Mr. C. R. Bicknell in connection with the "Dual" lamp was of interest. At the moment in the author's experience it was new and its eventual sphere of usefulness yet to be completely defined. It was applicable, of course, to both street and industrial lighting, and to some extent stood midway between the tungsten filament lamp and the mercury discharge lamp. In considering which particular type of lamp should be used for a particular installation, the efficiencies of the lamps and any special circumstances, such as cost of power, would help to decide which lamp should be used.

The author did not join with Mr. Bicknell in regarding the choke as a criminal element. It was a very reliable piece of apparatus, of a cost that was low when spread over the usual period of time allowed for amortisation, and whose use definitely enabled high efficiencies to be obtained. For example, the overall efficiency of the 400-watt mercury vapour

lamp and choke is about 42.5 lumens per watt. Any attempt to eliminate the choke brought about a sacrifice in efficiency.

With regard to choke adjustment, this can, of course, be done by means of an adjustable airgap. It is, however, much less trouble to secure correct operating conditions by adjustment of a tapped connection. Any mercury vapour lamp will operate in the horizontal position without magnetic control if the mercury vapour pressure is kept sufficiently low. There is a definite gain in overall luminous efficiency in using a high-pressure lamp with external magnetic control over the lower pressure lamp without control.

In the stroboscopic experiment the flashes of red and greenish blue light were directed in rapid alternation on to a white background. The frequency of alternation was high, and in the absence of any standard of " white " the colours of the lights were sufficiently complimentary to give a " white " appearance to the card.

Mr. Scott had called attention to one possibility in the use of luminescent powders, but owing to the cost of the powders and other considerations it was perhaps better to use them as part of the lamp and obtain the "something for nothing" to which Mr. Scott had called attention. The " something " had to be what was required, and this necessitated considerable investigation into the luminescent response of various powders under various exciting radiations.

He agreed with Mr. Scott that the stroboscopic lamp would be of interest to mechanical and other engineers.

In reply to Mr. Dow, it is possible, using luminescent powders, to obtain from a discharge lamp giving initially but little light, efficiencies comparable with tungsten and ordinary discharge lamps. Indeed, it was fairly easy to construct lamps with efficiencies of 25 to 30 l.p.w., and it was possible to obtain experimentally combinations of discharge lamps and luminescent powders giving efficiencies considerably higher than this. When luminescent powder was used with a lamp already giving a high efficiency either a gain in efficiency was possible or an improvement in colour output. The luminescence outweighs the light obstruction due to the powder.

In conclusion, the author expressed his thanks to the Society and to the audience for their interest and helpful discussion.

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